CO$_2$ Injection in the Altmark Natural Gas Field, Germany: Simulations of Water Injection to Delay CO$_2$ Breakthrough

D. Rebscher[1], F. May[2], C.M. Oldenburg[1]

[1] Earth Sciences Division, Lawrence Berkeley National Laboratory [2] Bundesanstalt für Geowissenschaften und Rohstoffe, Germany

ABSTRACT

Numerical simulations of CO$_2$ injection into the nearly depleted Salzwedel-Peckensen (Sw/Pes) reservoir of the Altmark gas field, Sachsen-Anhalt, Germany, have been carried out to investigate the feasibility of carbon sequestration with enhanced gas recovery (CSEGR). The Sw/Pes gas reservoir is a faulted and compartmented anticlinal structure covered by a massive salt cap rock. The reservoir is composed of alternating sandstone, claystone, and siltstone at a depth of approximately 3000 m. The reservoir pressure and temperature are approximately 20 MPa and 120 °C. The average usable storage porosity in sand layers is estimated to be 8 %. Permeability varies from 10^{-12} m^2 in the sandy units to very low values in the clayey units. The natural gas is rich in nitrogen (N$_2$), ranging from 40-90 %, with an average methane (CH$_4$) content of 32 %. We have carried out reservoir simulations of CO$_2$ injection into a model reservoir with nine layers and six different rock types spanning 226 m of total thickness. The geometry modeled is a quarter of a five-spot pattern with a well spacing of 2.1 km. Various injection and production strategies were investigated. In general, the high-permeability layers allow breakthrough of CO$_2$ at the production well after 3–10 years. We tested the effects of pre-CSEGR water injection into the high-permeability layers for mobility control. The simulations suggest that water injection can be used to delay CO$_2$ breakthrough. In general, CSEGR appears to be promising for increasing gas production in the Altmark gas fields while simultaneously sequestering CO$_2$.

OBJECTIVES

The feasibility of carbon sequestration with enhanced gas recovery is investigated as a new strategy for mature natural gas fields in Germany due to
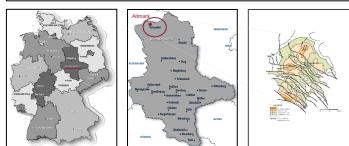
- decreasing gas production
- CO$_2$ emission trading starting in 2005 in the European Union

Numerical simulations are performed using the TOUGH2 module EOS7C with the parameters listed below. Note that the simulations assume pure CO$_2$ injection into pure CH$_4$ reservoir.
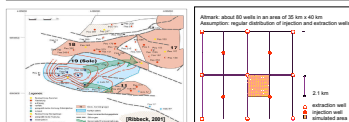
model parameter	value
number of injection wells in total	27
number of extraction wells in total	27
model type	5-spot-configuration
model area	2.1 km × 2.1 km
reservoir height	226 m
dip of layers	0 °
temperature	120 °C, constant
pressure	hydrostatic distribution
pressure at the bottom	20 MPa
duration of CO$_2$ injection phase	40 a
total CO$_2$ injection rate	420 · 10^6 t CO$_2$
CO$_2$ injection rate at one sink site	1.6 to 16 kg/s
geometry of source	vertical column
duration of CH$_4$ extraction	40 a, simultaneous to CO$_2$ injection
geometry of sink	vertical column

MATERIALS + METHODS

Salzwedel Peckensen, Altmark region, Sachsen-Anhalt, Germany

Well spacing and 5-spot discretization

Altmark: about 80 wells in an area of 35 km x 40 km
Assumption: regular distribution of injection and extraction wells

2.1 km

extraction well
injection well
simulated area

[Ribbeck, 2001]

Hydrostratigraphic units and 3D grid

Characteristics of the gas bearing sequences are based on a more complex geologic formation in the Western Altmark in depths of about 3000 m

Initial conditions

liquid saturation SL
diagonal plane through 3D grid
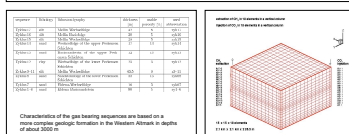
RESULTS

Migration of CO$_2$ through the reservoir

Injection of CO$_2$ (right-hand side of domain) and simultaneous extraction of CH$_4$ (left-hand side of domain) at eight times and the resulting CO$_2$ in the gas phase migrating from the extraction to the production well
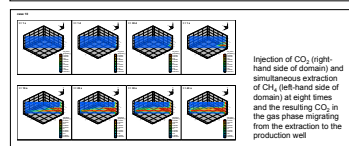
CO$_2$ at the production well and breakthrough times

Summary of results for the 11 cases with varying permeability of the layers
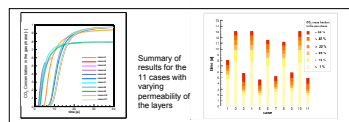
Water injection for mobility control

Injection of water (right-hand side of domain) and simultaneous extraction of CH$_4$ at eight times (left-hand side of domain) and the resulting liquid saturation
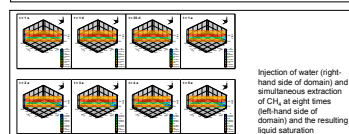
Different amounts of water injection

	case1	case2	case3	case4	case5	case6
Q [kg/s]		2.9091	5.8182	8.7273	11.6364	14.5455
Q compared to Q in case1	0	2 × bigger	3 × bigger	4 × bigger	5 × bigger
w_r [w/w cyl.=1]		0.7233	1.4491	2.1724	2.8990	3.6259
q_w [kg/s in cyl.1]		2.5967	4.3518	6.4767	6.6270	10.7957
time CO$_2$ in gas phase > 1%	5.75 a	4.96 a	5.07 a	5.16 a	5.26 a	5.51 a
time CO$_2$ in gas phase > 10%	6.80 a	6.39 a	6.01 a	6.13 a	6.28 a	6.44 a
time between CO$_2$ in gas phase > 1% till > 50%	3.30 a	3.39 a	3.49 a	3.69 a	3.77 a	3.98 a
delay of breakthrough for > 1%		0.213 a	0.324 a	0.316 a	0.329 a	0.506 a
delay of breakthrough for > 10%		0.266 a	0.409 a	0.568 a	0.663 a	0.841 a
considered time	40 a	40 a	40 a	40 a	45.1 a	40 a
machine	P-4 [1]	P-4 [1]	P-4 [1]	P-4 [1]	P-4 [1]	P-4 [1]
number of time steps	2341	318	369	421	38503	1493
calculation time	6136 s	7246 s	10866 s	9632 s		15288 s

(1) = Intel(R) Pentium(R) 4 CPU 2,80GHz 512 KB, LINUX

CONCLUSION

The numerical simulations of CSEGR indicate that the Altmark area in the North German Basin is a suitable reservoir for CO$_2$ storage.

In the simplified 3D model the CO$_2$ breakthrough occurs first through the high permeability layers within 3 a to 10 a.

With appropriate injection and extraction strategies, e.g. by injecting water in the high permeability layers before injecting CO$_2$, the CO$_2$ breakthrough can be retarded for about another year.

For more specific results, a detailed model should be developed based on site-specific industrial data.

In general, CSEGR appears to be promising for increasing natural gas production in the Altmark reservoirs while simultaneously sequestering CO$_2$.

REFERENCES

Oldenburg, C. M, and S. M. Benson, CO$_2$ Injection for Enhanced Gas Production and Carbon Sequestration, Soc. Petrol. Eng., SPE 74367, 2001

Pruess, K., C. Oldenburg, and G. Moridis, TOUGH2 User's Guide, Version 2.0, Lawrence Berkeley National Laboratory Report, LBNL-43134, Berkeley, CA, November 1999

Ribbeck, H., Natural Gas Storage Project at Peckensen, Germany - Part 1, Spring 2001 Technical Class, 22 April 2001, Orlando, Florida, USA

ACKNOWLEDGEMENTS